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A LIMITED EVALUATION OF ULTRASONIC SPOT WELDS IN X2020-T6 ALUMINUM ALLOY SHEET

REPORT A461 SERIAL NO. 3

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A LIMITED EVALUATION OF ULTRASONIC SPOT WELDS IN X2020-T6 ALUMINUM ALLOY SHEET

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ABSTRACT

Ultrasonic welding, a newly developed, solid state, non-fusion process for joining sheet metals without solders, fluxes, or filler metals appears to be superior in some respects to electrical resistance welding. A limited evaluation of specimens of X2020-T6 aluminum alloy, furnished to M.A.C. by Alcoa's Research Laboratories, indicates that more comprehensive test work should be done in an effort to qualify this process for manufacture of production parts of various structural alloys at M.A.C.

A LIMITED EVALUATION OF ULTRASONIC SPOT WELDS IN X2020-T6 ALUMINUM ALLOY SHEET

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1. SUMMARY:

A limited evaluation of ultrasonically spot welded specimens of X2020-T6 aluminum alloy, furnished to M.A.C. by Alcoa Research Laboratories, has been completed. Specimens consisted of single spot lap shear, overlapping spot seams across 3/4" wide strips, and overlapping spot seams lengthwise of 3/4" wide strips.

Evaluation consisted of strength tests of the single spots and the overlapping spot seam welds across the specimen width. Metallographic examinations were made of the longitudinal overlapping spot seam specimens and of the cross seam welds after the strength test.

top 5

Results were encouraging in that strength tests indicate superior strength of the ultrasonic welds in comparison to electrical resistance welds. Deformation is slight, and the welds are free of cracks and internal voids.

In order to qualify the process for use at M.A.C., further test work is required to establish fatigue characteristics and the application of the method to various structural alloys and thicknesses.

2. INTRODUCTION:

Ultrasonic welding is a non-fusion, solid state process for joining metals without the aid of solders, fluxes, or filler metals. The work pieces are clamped at relatively low static pressure between a sonotrode and an anvil; ultrasonic energy is delivered to the joint zone through the sonotrode for a brief interval, usually a fraction of a second, to accomplish the weld. A metallurgical bond is produced which does not have the cast metal and heat affected zones characteristic of fusion and resistance welding. Indentation of the surface is very slight and mechanical properties of the material are not appreciably affected.

Development of the process has taken several years, starting with foil gauges of aluminum and progressing to a thickness of .125 inch. In addition to joining aluminum, other metals and combinations of metals can be ultrasonically bonded.

Some of the advantages claimed for the ultrasonic welding method are as follows:

Dissimilar metals may be joined
Thin sheets may be joined to heavy sections
Low clamping forces required result in only slight external deformation
Electrical power requirements are relatively low
Cold work or heat treat properties are retained in the weld zone
Pre-weld cleaning is minimized

Ultrasonic spot welding equipment is commercially available in sizes up to 4000 watts. The 4000 watt machine will handle the high strength aluminum alloys up to .080 inch thick for the thinner member. Ultrasonic roll seam welders have been developed and can be supplied to meet special applications.

This new method of welding is of particular interest to M.A.C. for the fabrication of continuous gas tight welds in high strength heat treated materials without impairment of mechanical properties.

3. WORK PERFORMED:

At the request of M.A.C. Advanced Design, specimens of ultrasonically welded X2020-T6 aluminum alloy sheet were obtained from Alcoa Research Laboratories for evaluation. Examples of single spot and overlapping spot seam welds were furnished. Material thicknesses were: .010 to .010, .025 to .025, and .010 + .010 to .032. Figures 1, 2, and 3 show the configuration of the test specimens. All of the welds in the specimens furnished for this evaluation were performed on a 2 KW ultrasonic spot welder using a 3" standard tip.

After close examination of the specimens to observe surface appearance and record visible cracks, pits, or other defects, destructive tests were performed to determine mechanical and metallurgical characteristics of the welds. Destructive testing consisted of the following:

(a) Lap shear strength of the single spot welds

(b) Tensile strength tests of the specimens having an overlapping spot seam weld across the specimen width.

(c) Metallographic analysis of those specimens having the overlapping spot seam weld in the length direction of the specimen.

(d) Metallographic analysis of the transverse spot seam welds after the tensile test.

(e) Photomacrographs and photomicrographs to illustrate metallurgical effects and conditions at the surface and interface of the weld area.

(f) Micro hardness checks with the Wilson "Tukon" Hardness Tester to determine whether a significant amount of cold working results from ultrasonic joining.

Specimen dimensions and weld data are shown in Table I. Test work was performed by the Materials and Methods Section of M.A.C. GED Laboratories Department 655.

4. RESULTS:

Results of the strength tests are shown in Table I.

The single spot lap shear specimens were pulled as received from Alcoa. The transverse overlapping spot seam welded specimens were machined in the form of standard two inch gauge length tensile specimens at M.A.C.; the gauge section being .500" side with the weld at the center of the gauge section and across the full width.

The weld section pulled out clean in all of the single spot lap shear specimens.

The transverse overlapping spot seam weld specimens failed in a jagged line closely following the weld zone contour at the edge of the weld.

There was no indication of weld interface failure in any of the specimens.

Specimen weldment configuration is shown in Figures 1, 2, & 3.

Photographs reproduced in Figures 4, 5, 6, & 7 show typical conditions of weld structure and fit up.

Hardness tests made on specimen number $C_3 1$, .010 + .010 to .032 thicknesses, are recorded on Figure 8.

Figures 9 and 10 illustrate typical appearance of single spot and overlapping spot seam welds.

Weld grain structure at the material face and at the weld interface are shown in Figures 11 and 12.

5. DISCUSSION:

5.1 Physical Appearance

The surface appearance of ultrasonic spot welds is very similar to resistance spot welds. Electrode pick-up is somewhat of a problem and causes the surface to appear rougher than it actually is. Surface indentation is very slight; however, attached small thin flakes or ribbons at the edge of the weld area were present on most of the specimens received from Alcoa (See Figures 9 & 10). These flakes appear to be caused by the sliding action of the sonotrode on the surface of the weldment and if characteristic of the method would present the problem of removal prior to post weld surface treatment. It is probable that proper control of weld procedure would eliminate this condition.

Distortion or warpage is very slight and the sheets surrounding the weld zone remain in close contact.

Surface preparation of the specimens prior to welding consisted of scratch brushing both surfaces of each component. Although this method apparently produces good welds, it is probable that cleaning of the mating surfaces only would produce similar weld results but might reduce tip sticking or pick-up.

Other than tiny pits caused by sonotrode pick-up, and the flaking caused by sonotrode movement, the only visible defect was a crack from the specimen edge to the first spot of one of the .010 + .010 to .032 specimens which had the overlapping spot seam weld running across the 3/4" specimen width. This crack was apparently caused by an edge distance too short for the pressure and power used. The crack did not extend into the weld. See Figure 3, Specimen $C_2 1$.

5.2 Metallographic Examination

Metallographic examination of weld cross sections of the overlapping spot seams, for both longitudinal and transverse direction, revealed no cracks, voids, or conditions known to be detrimental to weld quality.

What is apparently the joint interface is readily discernible in most of the specimens as shown in Figures 4, 5, and 6. The clarity of the interface line is apparently a function of the degree to which the oxide film, finely disintegrated by the ultrasonic vibration and friction, is diffused into the grain structure of the metal. In some cases the line has disappeared completely with grains formed across the interface in homogeneous structure. Even where the line is clearly discernible, the grain structure bridges the interface. Figures 4, 5, 6, and 11 illustrate this condition very clearly.

One phenomenom of this method of joining is the tendency of the interface line to drift in an irregular manner, as shown in Figure 4, without significant change in overall material thickness. One explanation offered is that possibly the grains lose their cohesion during the ultrasonic vibration and act like a bowl of sugar in the weld section, permitting some freedom of movement for reorientation of grains and displacement of the broken oxide film.

The strength tests developed no cracks or separations at the interface line and the results of this investigation indicate that the presence of the line may have no material effect on the joint strength. Further tests, particularly for fatigue conditions, with specifically designed specimens, would be required to prove the validity of this conclusion.

What appeared, from the macrographs and micrographs, to be severe cold working at the surface of the weld zone prompted micro hardness testing to determine the effect of ultrasonic welding on material hardness. These tests were made on a mounted transverse cross section of specimen C_31, Figure 8. The results recorded on Figure 8 show a loss in hardness rather than work hardening. Figure 12, (M-60-2104), Specimen C_21, shows the sub-surface condition magnified 250 times.

The higher magnification of Figure 12 (M-60-2104) shows that, rather than cold work, the surface condition is caused by an extremely agitated grain structure, sometimes forming eddies or swirls in which grain boundary material is accumulated. Examination of micrographs of the etched specimens indicates that the grain boundary material is affected by ultrasonic energy. In some instances there is considerable refinement of the grain structure; however, in general, at the weld interface there is no significant change in grain shape or size. Application of etchant to the polished metallographic specimen increases the sharpness of grain boundary outlines in the weld zone thereby clearly defining it.

Although orientation or position of the sheet faces relative to the sonotrode, or power input member, during welding of the specimens of this evaluation is not known, it is assumed that the greatest effect on surface condition and grain structure is on the power input side.

5.3 Mechanical Evaluation

Although the quantity of specimens available for test was small, the results of the strength tests indicate that ultrasonic spot welding compares ~~very~~ favorably with electrical resistance spot welding. Direct comparison can be made from the .025 to .025 single spot welds with X2020-T6 aluminum alloy resistance spot weld results reported in M.A.C. Report 6785, page 22. Thirty single spot resistance welds averaged 405 pounds lap shear strength [of joints], ranging from 329 pounds to 453 pounds. The three ultrasonic spot welds for .025" thick X2020-T6 alloy of the present evaluation averaged 553 pounds with a range of 538 to 566 pounds. Comparisons for the other sheet combination listed in Table I of this report are not available.

Tensile tests of the overlapping spot seam ultrasonically welded specimens indicate that strength approaching the ultimate tensile strength [of joints] of the unwelded material is obtained. Specimen configuration is shown with Table I. Results of tensile strength test of X2020-T6 alloy recorded in M.A.C. Report 6785 show an average ultimate tensile strength of 73,500 p.s.i. for .063 inch thick material. Considering the effect of bending stresses caused by eccentric loading of the lapped joint, slight thinning in the weld area due to the welding operation, and stress concentration at the sharp notch created at the junction of the weld and the joint interface, the failing strengths of 51,050 to 66,200 p.s.i. for the three combinations tested appear to be quite high and may approach the base material ultimate tensile strength for the foregoing conditions. All of these specimens failed in the same manner, in a line closely following the edge of the weld. Figure 7 shows cross sections made at the weld center line across the specimen after failure. No evidence of weld separation or failure was evident.

6. CONCLUSIONS AND RECOMMENDATIONS:

Results of the work described in this report indicate that ultrasonic spot welds in X2020-T6 aluminum alloy sheet are stronger than electrical resistance spot welds made in the same type alloy. However, direct comparison could be made only for material thickness of .025 inch.

Although ultrasonic joining significantly softens the X2020-T6 alloy in the weld zone, deformation and indentation are slight and strength properties do not appear to be materially affected.

The joint interface line does not disappear completely in most ultrasonic welds; however, this condition has not been shown to affect joint strength.

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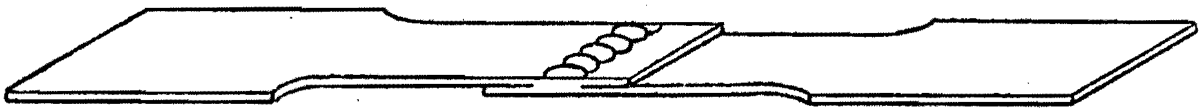
In view of the results of this evaluation and the advantages claimed for the process, Department 684 will continue to keep abreast of the state-of-the-art on ultrasonic welding. Future evaluation of the process will be conducted under Engineering Study Authorization E9661-007, "General Weld Improvement and Development."

Spec. No.	Weld Configuration	Material Thickness (inch)	Spec. Gauge Width	Failing Load (Pounds)	MIL-W-6858A Req.	Failing Stress (p.s.i.)	Weld Time (Sec.)	Clamp. Load (Pounds)	Power (Watts)
$A_1$1	Single Spot	.010 to .012	-	197	60	-	.2	500	1300
$A_1$2	Single Spot	.011 to .011	-	153	60	-	.2	500	1300
$B_1$1	Single Spot	.025 to .026	-	538	148	-	.35	500	1800
$B_1$2	Single Spot	.025 to .026	-	566	148	-	.35	500	1800
$B_1$3	Single Spot	.026 to .026	-	555	148	-	.35	500	1800
$C_1$1	Single Spot	.011 plus .011 to .033	-	485	-	-	.8	500	1900
$C_1$2	Single Spot	.011 plus .011 to .032	-	485	-	-	.8	500	1900
$A_2$1	Trans. Seam	.011 to .011	.500"	364	-	66,200	.2	500	1300
$A_2$2	Trans. Seam	.011 to .011	.500"	310	-	56,300	.2	500	1300
$B_2$1	Trans. Seam	.026 to .026	.501"	665	-	51,050	.35	500	1800
$C_2$1	Trans. Seam	.011 plus .011 to .032	.501"	634	-	57,500	.8	500	1900

TABLE I

SPECIMEN DATA - ULTRASONIC WELDS IN X2020-T6 ALUMINUM ALLOY SHEET



CONFIGURATION OF SPECIMENS $A_2$1, $A_2$2, $B_2$1 & $C_2$1

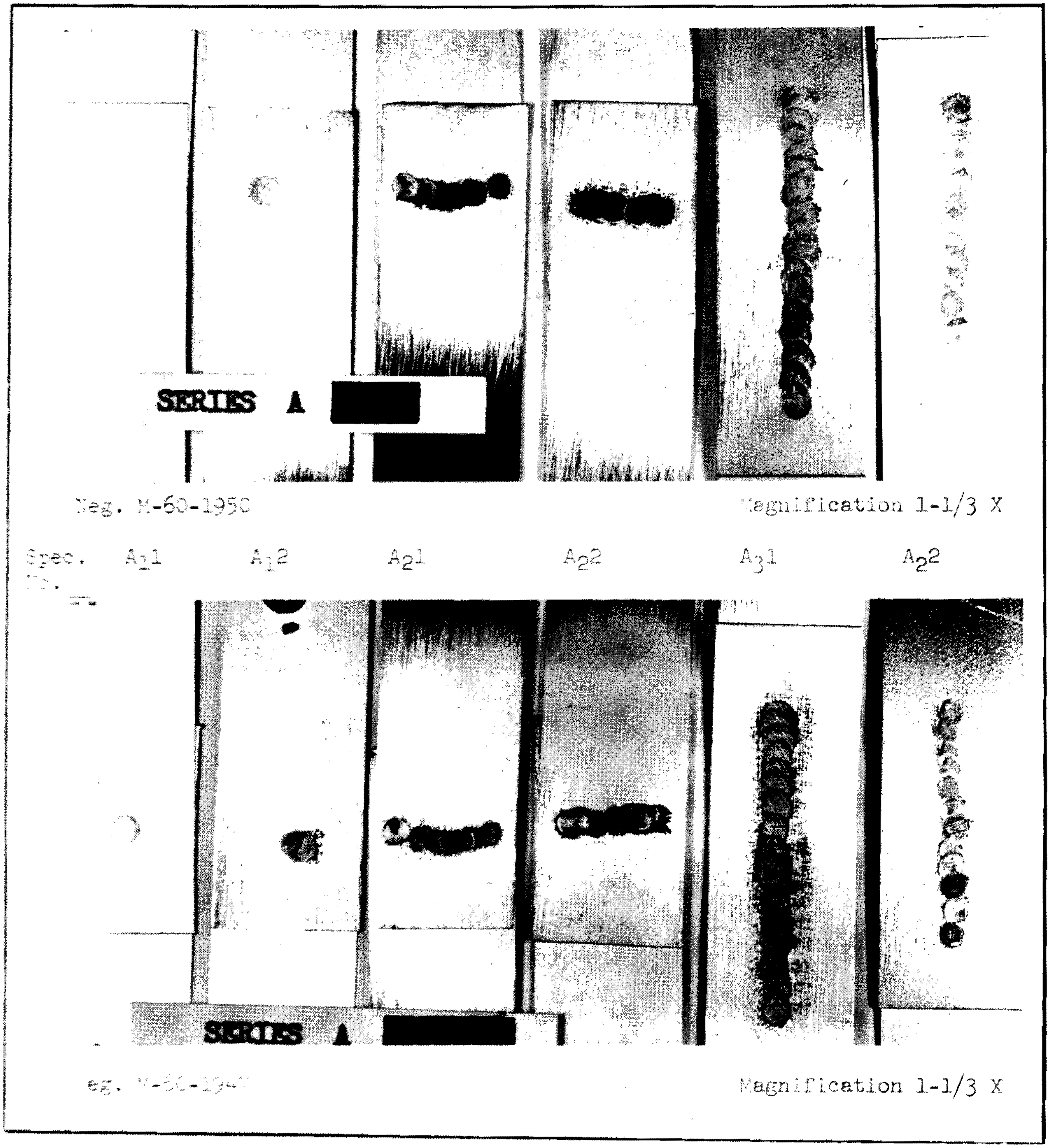


FIGURE 1

ULTRASONIC WELD CONFIGURATION OF
.010" TO .010" SPECIMENS SHOWING BOTH FACES OF WELDS

MATERIAL - X2020-T6 ALUMINUM ALLOY SHEET

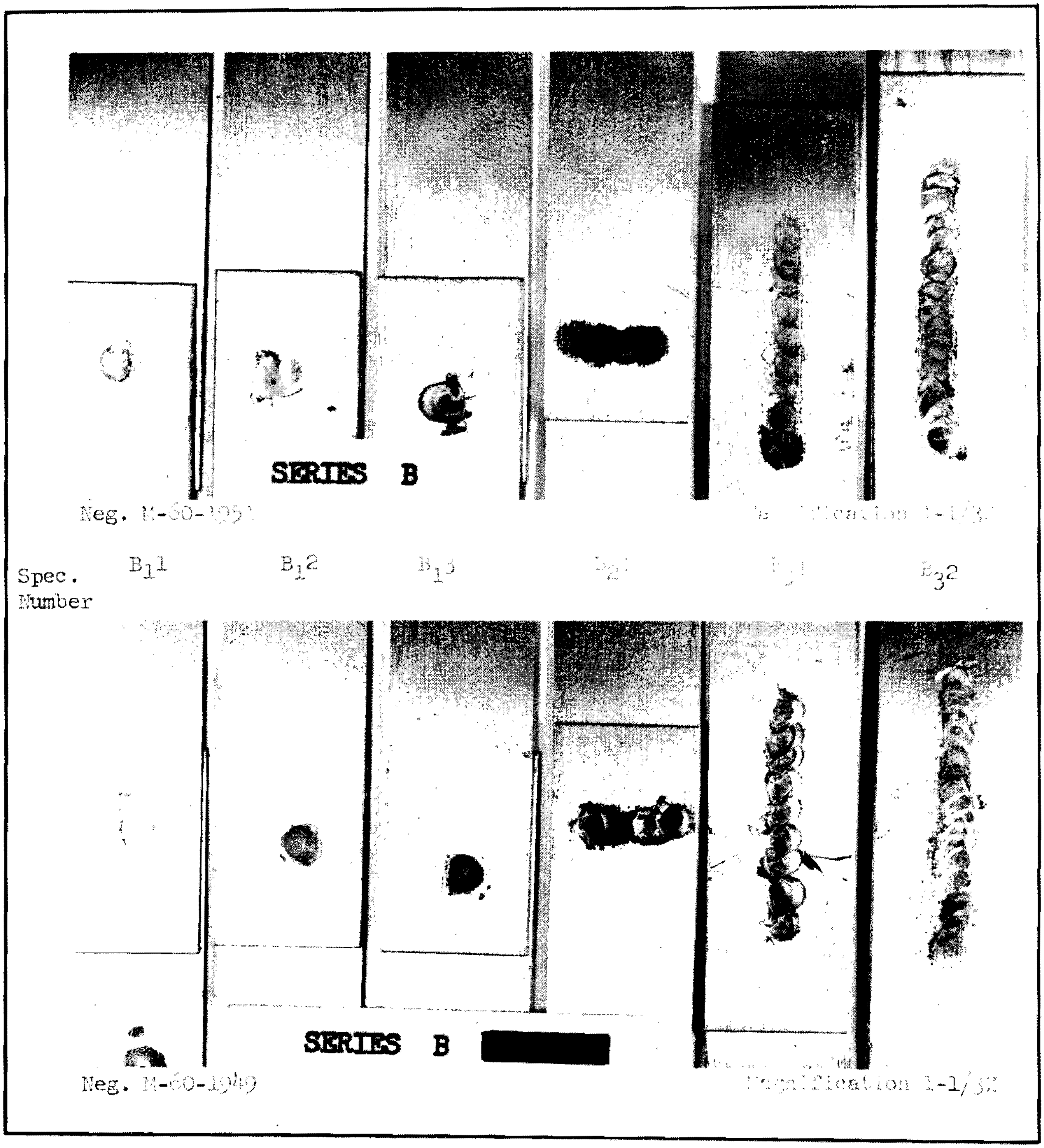
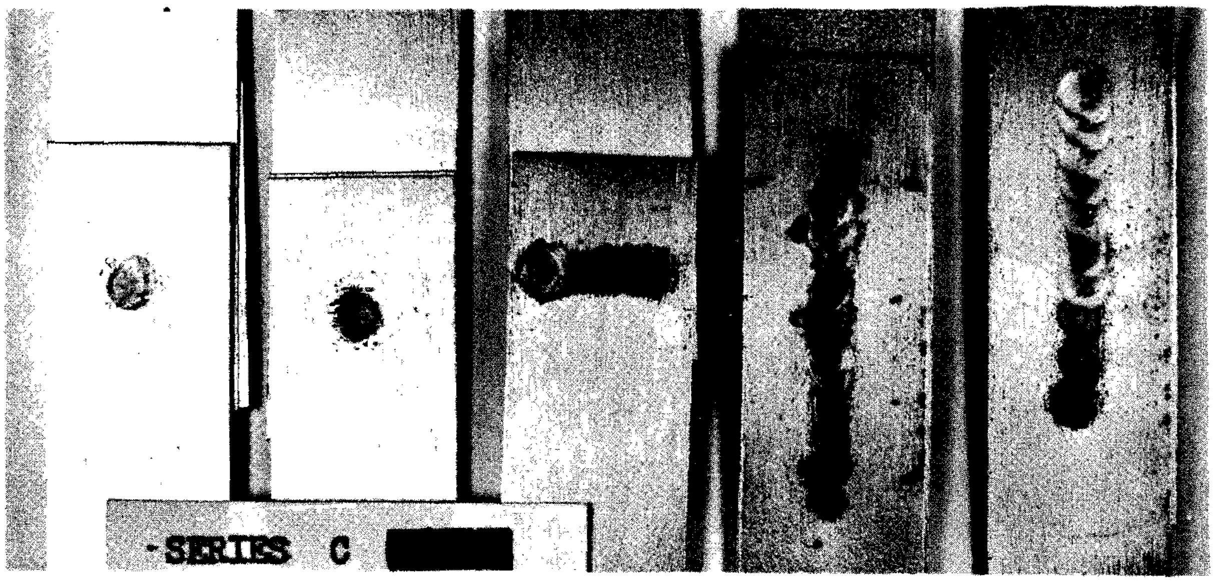


FIGURE 2

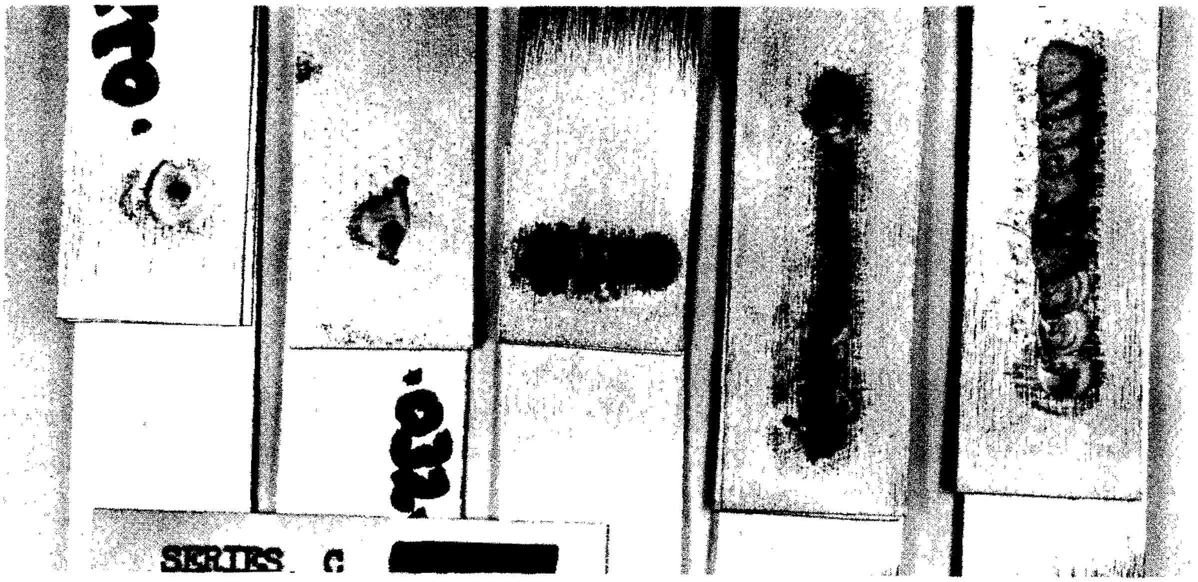
ULTRASONIC WELD CONFIGURATION OF
.025" TO .025" SPECIMENS SHOWING BOTH FACES OF WELDS

MATERIAL - X2020-T6 ALUMINUM ALLOY SHEET



Negative M-60-1946 Magnified 1-1/3X

Spec. Number $C_1 1$ $C_1 2$ $C_2 1$ $C_3 1$ $C_3 2$



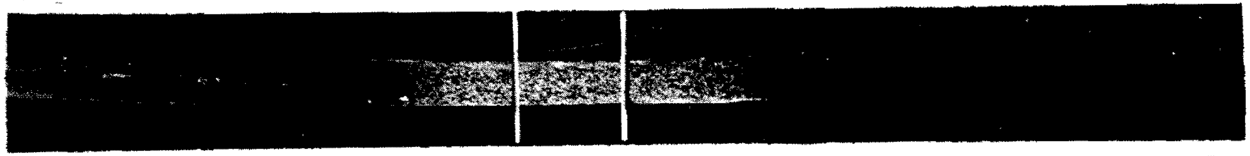
Negative M-60-1948 Magnified 1-1/3X

FIGURE 3

ULTRASONIC WELD CONFIGURATION OF .010" + .010" TO .032" SPECIMENS SHOWING BOTH FACES OF WELDS

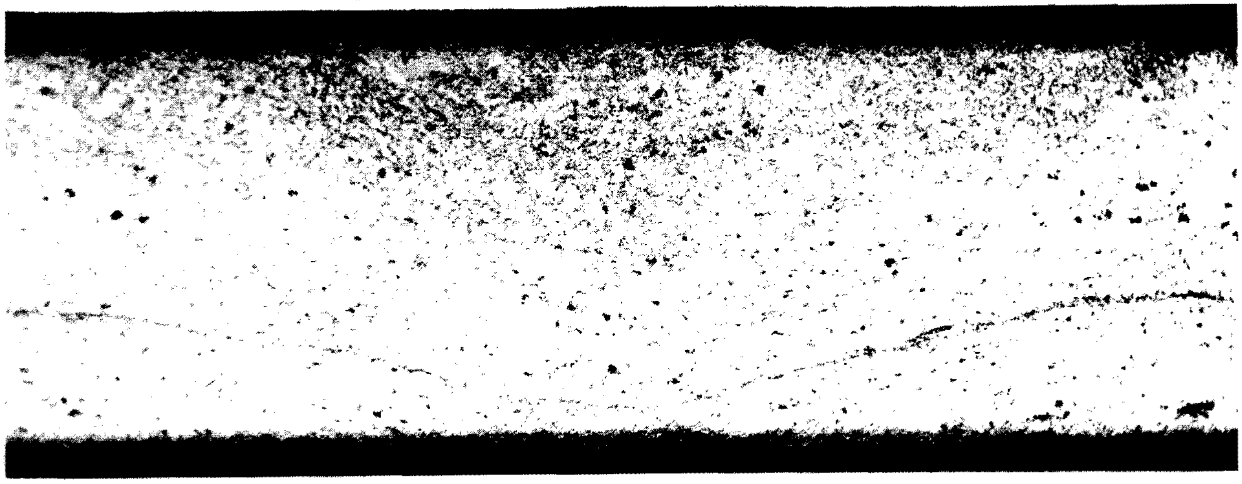
MATERIAL - X2020-T6 ALUMINUM ALLOY SHEET

Negative M-11-202[illegible] Magnification 100X

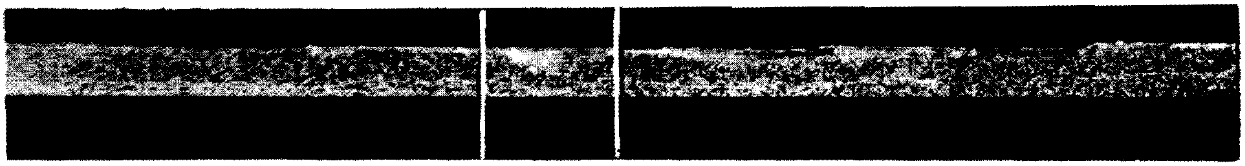


Negative M-11-2[illegible] Magnification 12X

SPECIMEN A_31, TRANSVERSE SECTION THROUGH WELD



Negative M-11-2029 Magnification 100X



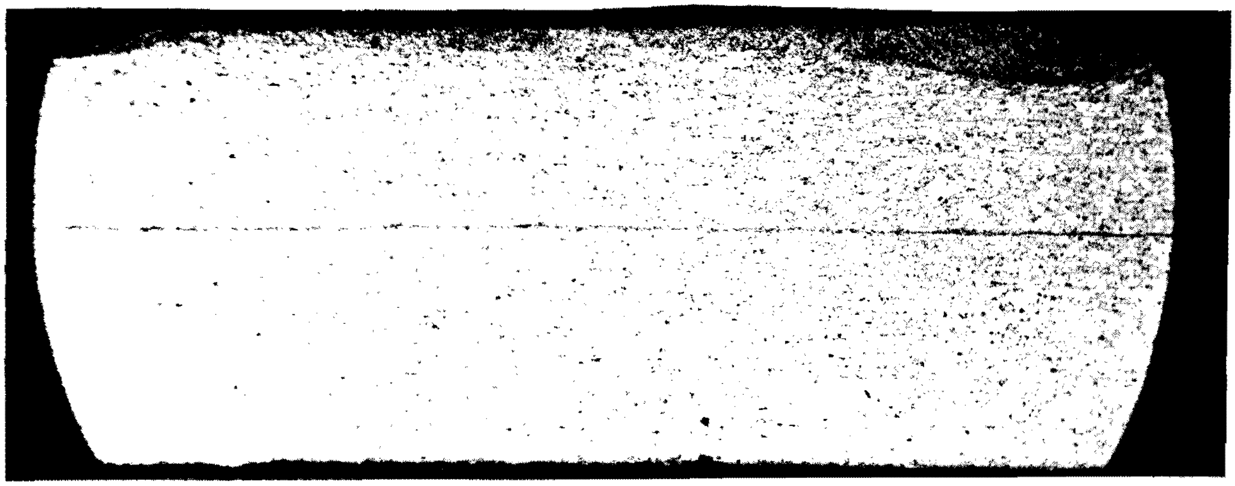
Negative M-11-2[illegible] Magnification 12X

SPECIMEN A_31, LONGITUDINAL SECTION THROUGH WELD

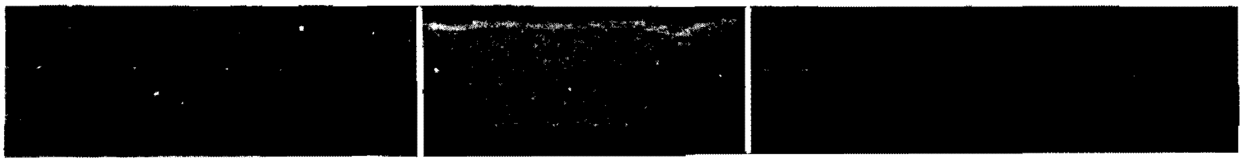
FIGURE 4

METALLOGRAPHIC STUDIES OF WELD CROSS SECTIONS SHOWING INTERFACE DRIFT

MATERIAL - X2020-T6 ALUMINUM ALLOY SHEET .010" TO .010"

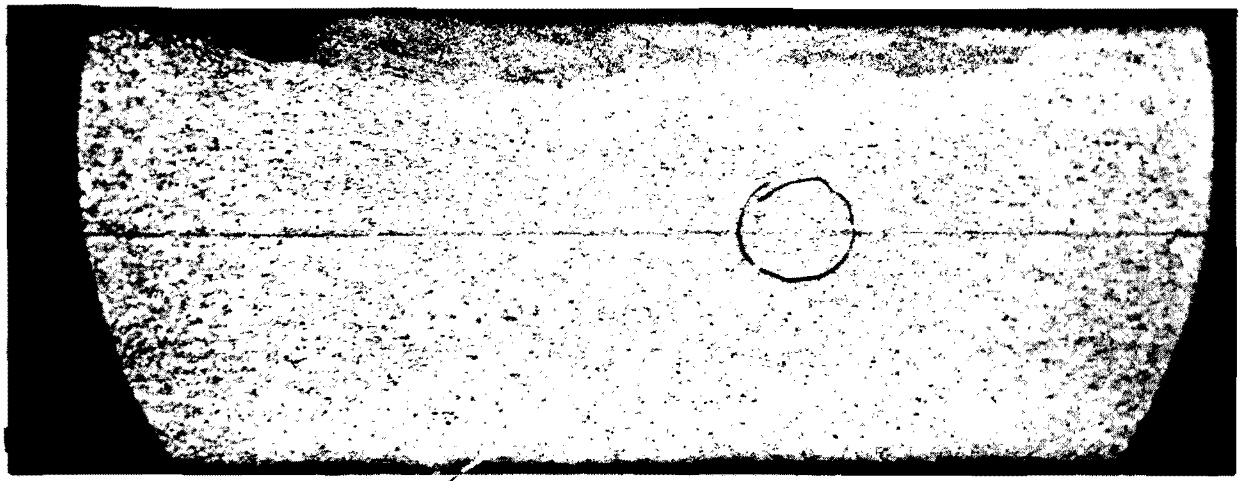


[illegible] Magnification 100X

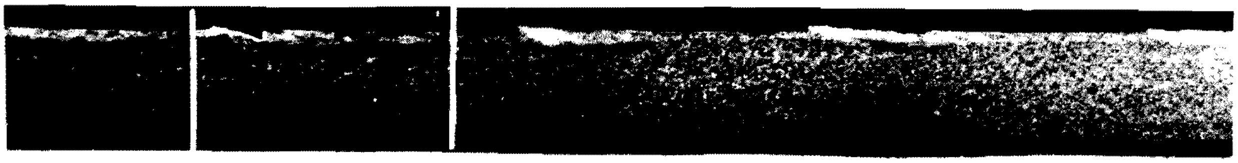


[illegible] Magnification [illegible]

[illegible]



[illegible] Magnification 100X



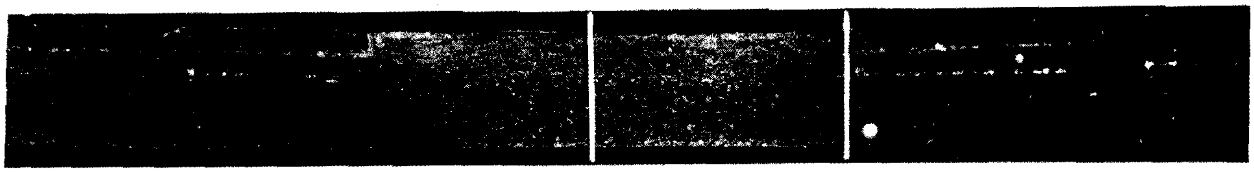
[illegible] Magnification 12X

[illegible]

FIGURE 5

METALLOGRAPHIC STUDIES OF WELD CROSS SECTIONS
OF .025" TO .025" X2020-T6 ALUMINUM ALLOY SHEET

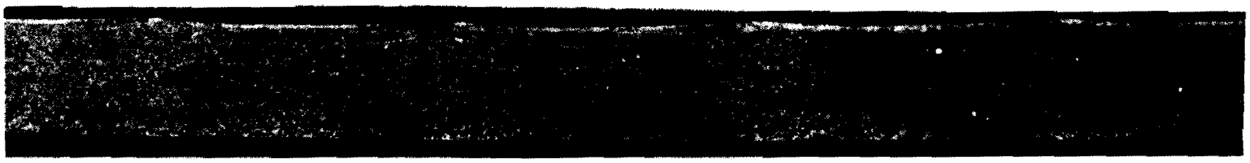
Negative M-[illegible] [illegible]



Negative [illegible] Magnification [illegible]

[illegible] 2, ABUT[illegible]

Negative M-[illegible]0-20[illegible] Magnification 50X



Negative M-[illegible]0-2052 Magnification 12X

SPECIMEN C$_3$2, LONGITUDINAL SECTION [illegible]

FIGURE 6

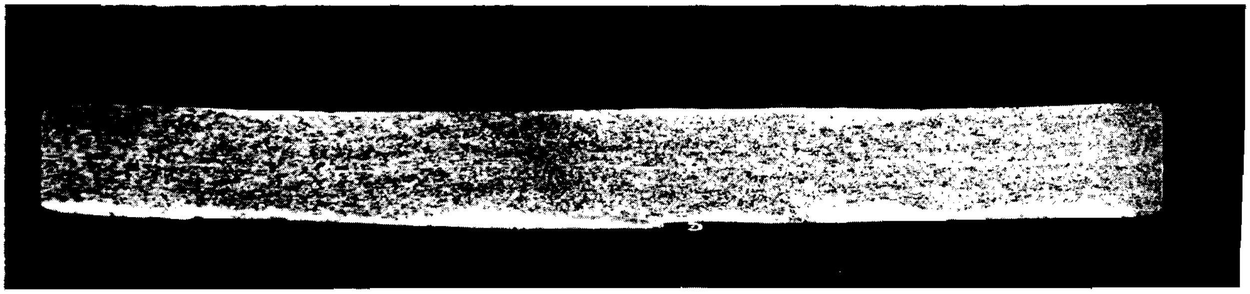
METALLOGRAPHIC STUDIES OF WELD CROSS SECTIONS
OF .010" PLUS .010" TO .032" X2020-T6 ALUMINUM ALLOY SHEET

Negative [illegible] Magnification 12 X

[illegible] Ag, .010" [illegible] .010"

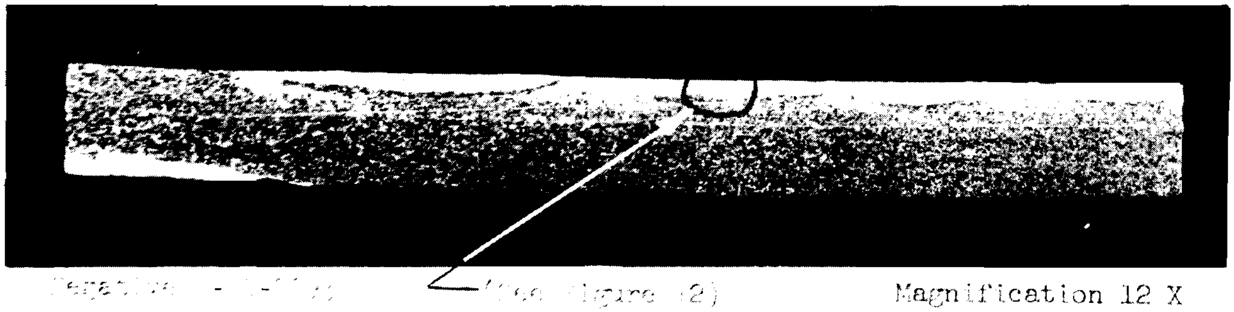
Negative [illegible] Magnification 12 X

[illegible] Ag2, .010" [illegible] .010"



Negative [illegible] Magnification 12 X

[illegible] Ag4, .025" [illegible] .025"



Negative [illegible] (See Figure [illegible]2) Magnification 12 X

[illegible], .[illegible]" AND .010" [illegible] .032"

FIGURE 7

CROSS SECTIONS THROUGH LONGITUDINAL CENTERS
OF WELDS AFTER STRENGTH TEST

MATERIAL - X2020-T6 ALUMINUM ALLOY SHEET

Negative M-60-2036 Magnification 50 X

TRANSVERSE CROSS SECTION OF SPECIMEN C$_3$1 MATERIAL -
X2020-T6 ALUMINUM ALLOY, .010" + .010" TO .032" SHEET

DIAGRAM BELOW SHOWS TUKON HARDNESS TAKEN IN ULTRASONIC WELD ZONE AND ALSO AT EDGE OF SPECIMEN OUTSIDE OF AFFECTED ZONE.

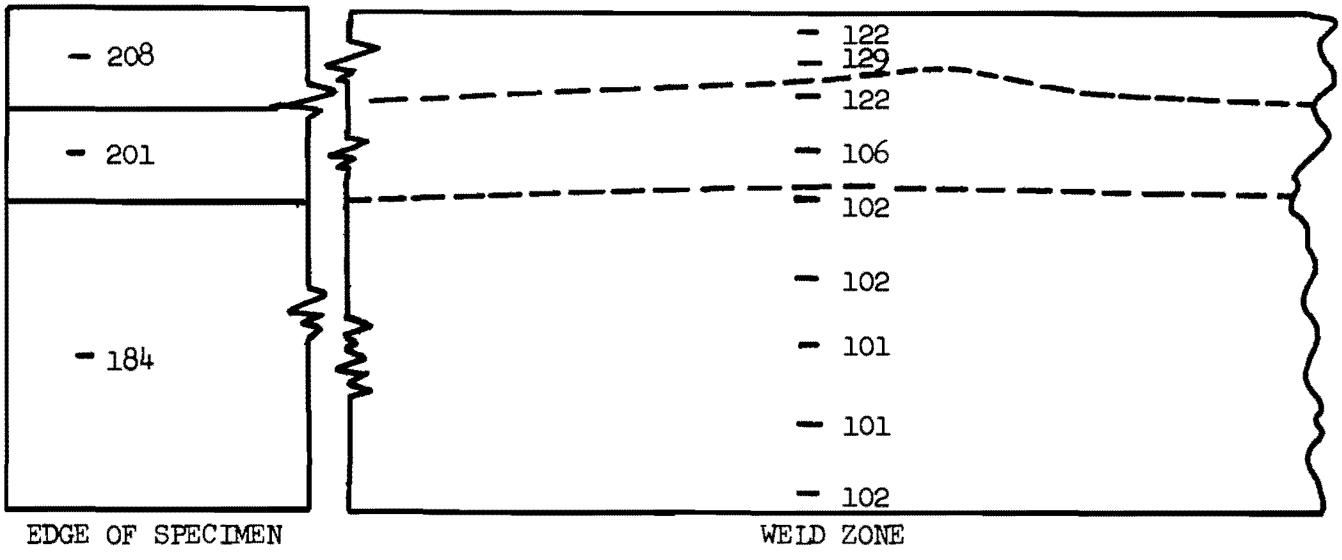


FIGURE 8

TUKON HARDNESS RELATIONSHIP OF WELD ZONE
AND BASE METAL. LARGER NUMBERS INDICATE GREATER HARDNESS.

Negative M-60-1970 Mag. 12.5X

Negative M-60-2009 Mag. 12.5X

FIGURE 9

VIEWS OF BOTH SIDES OF ULTRASONIC OVERLAPPING SPOT
SEAM WELD IN X2020-T6 ALUMINUM ALLOY, .010" TO .010" SHEET

SPECIMEN NO. $A_2 2$

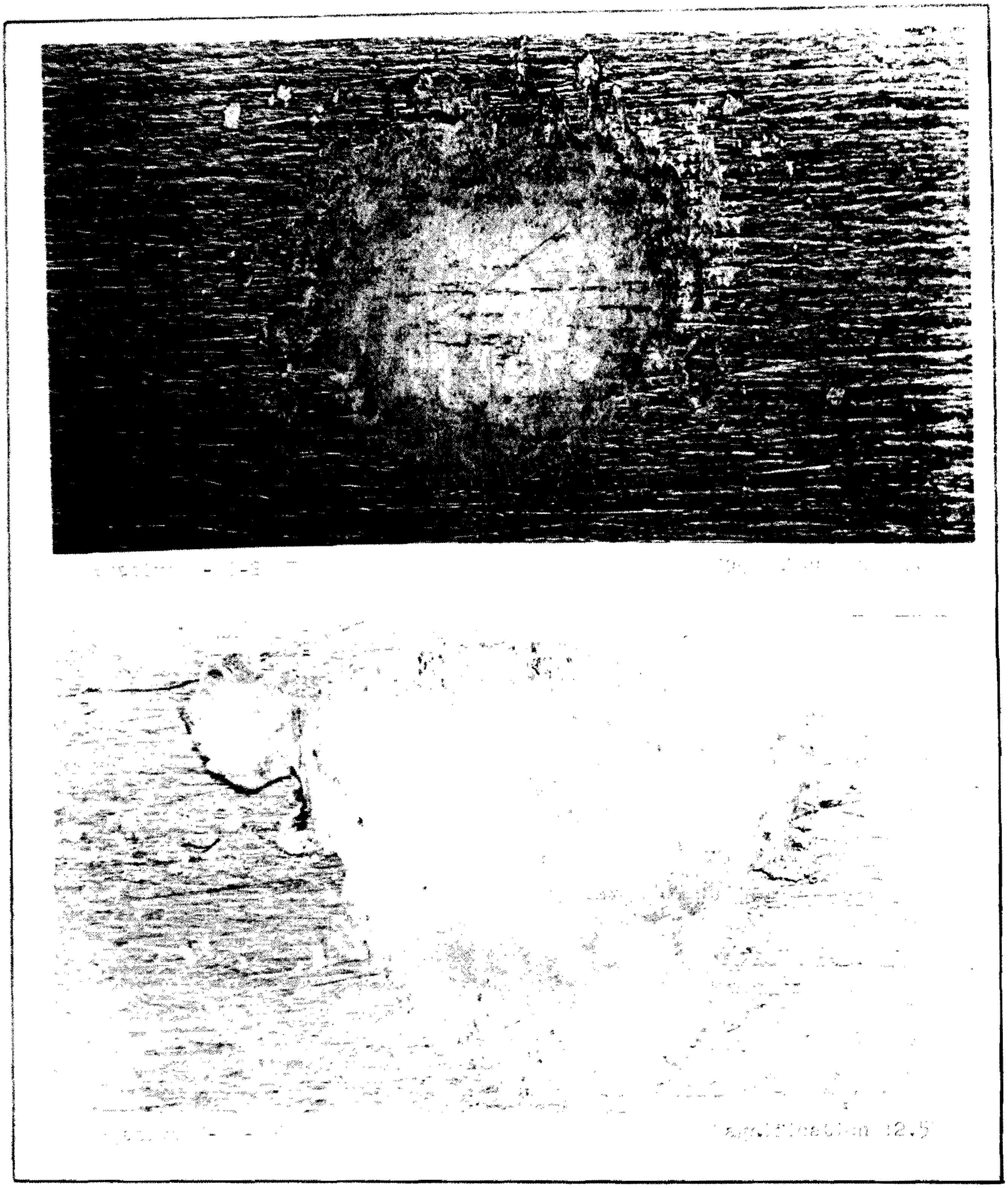


FIGURE 10

ENLARGED VIEW OF BOTH SIDES OF SINGLE SPOT ULTRASONIC WELD IN X2020-T6 ALUMINUM ALLOY SHEET, .010" + .010" TO .032". TYPICAL CONDITION SHOWING EXPULSION AT WELD FACE.

SPECIMEN NO. $C_1 2$

Magnification 250X

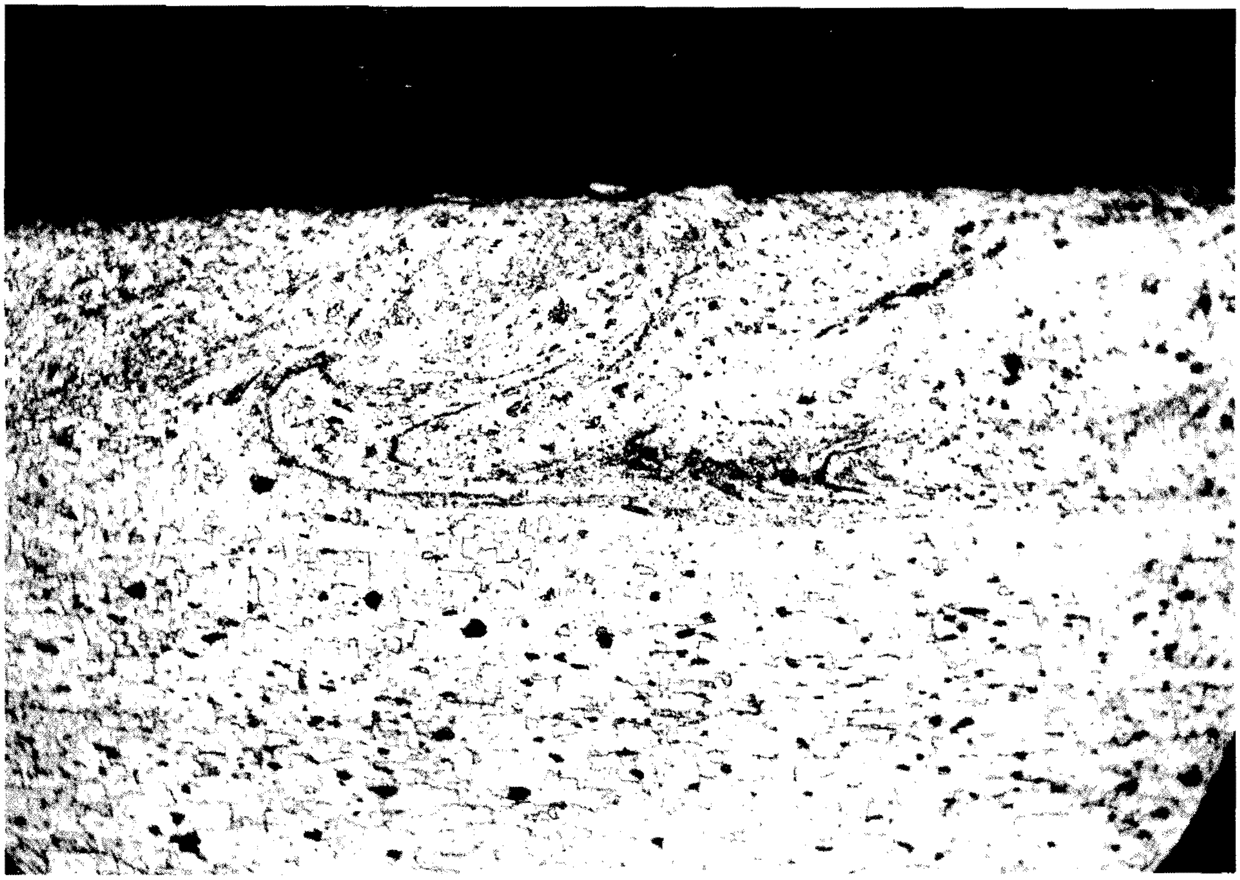
[illegible]

Magnification [illegible]

[illegible]

FIGURE 11

TYPICAL CROSS SECTIONS THROUGH WELD INTERFACE
OF ULTRASONIC WELDS IN X2020-T6 ALUMINUM ALLOY SHEET



Negative M-60-2104 Magnification 250X

FIGURE 12

CROSS SECTION OF ULTRASONIC WELD AT .010" + .010" FACE OF SPECIMEN C_21, .010" + .010" TO .032" X2020-T6 ALUMINUM ALLOY SHEET, SHOWING TYPICAL GRAIN STRUCTURE CLOSE TO THE SURFACE